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(54) **Control system.**

(57) A control system, capable of improving a disturbance response characteristic, includes a control processing unit and a power converter, the control processing unit includes a block for providing a signal A equal to a predetermined transfer function GX(S) of a detected value of a controlled variable n, a block for providing a signal B equal to a transfer function (1 + GX(S).GLH(S)) of a first command value and a block for providing, as a second command value, a difference T* between said A and B signal, where GLH(S) is a simulated transfer function which is from T* to n, the power converter controls the controlled variable according to the second command value.

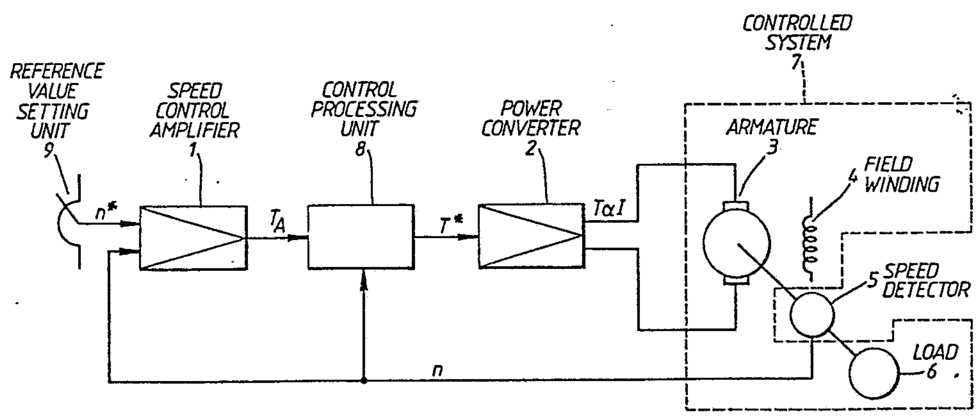

FIG.3.

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CONTROL SYSTEM

This invention relates to a system for controlling a controllable variable and, in particular, to an electric motor speed control system.

In this specification, the invention will be described taking a motor speed control system as an example.

In a motor speed control system, a speed detector coupled to the motor is usually provided, and the detected speed value derived from the detector is compared with a speed command value so that the current of a power converter is controlled, whereby a feedback control is performed.

Figure 1 of the accompanying drawings shows a fundamental configuration of a speed control system that controls the speed of a DC motor in a feedback control fashion.

Reference numeral 1 designates a speed control amplifier, 2 a power converter, 3 and 4 the armature and a field winding of the DC motor, respectively, 5 a speed detector, and 6 a load. An exciting circuit for the field winding 4 is not shown. The power converter 2 includes controlled rectifiers, choppers and a current control circuit that controls an output current I.

Here, it is assumed that the power converter 2 can be regarded as a current amplifier that controls the output current thereof in accordance with a current command value.

The speed control amplifier 1 receives a speed command signal n* which is produced in a reference value setting unit 9, and a detected speed signal n, so as to produce a torque command value signal T* corresponding to a torque value required for the motor. In the case of a DC motor, its torque and armature current are in a proportional relationship so that the torque command value signal T* is inputted to the power converter 2 as the current command value signal.

This causes the power converter 2 to feed the current I into the armature of the motor, so that the motor produces a torque proportional to the torque command value signal T*, whereby the speed thereof is varied. This speed n is detected by the speed detector 5 and fed back to the speed control amplifier 1.

The predominant facts as characteristics of the speed control system are such that the motor speed can respond rapidly and accurately in response to changes in the speed command value and that the motor speed change in response to variations in the load can be kept to a minimum and the motor speed can be rapidly returned to its original value. The former is defined as a command value response character~~istic~~, and the latter a disturbance response characteristic. The predominant component to determine these system characteristics is the speed control amplifer 1.

The conventional speed control amplifier is usually a so-called control amplifier, such as a proportional control amplifier, a proportional integral control amplifier, or a proportional integral control amplifer with compensation for anti-overshoot.

Various alternative control amplifiers may be used depending on the requirements. However, these control amplifiers are designed such that a command value response is regarded as of major importance, and a disturbance response is, in general, slower than the command value response.

Figure 2 illustrates a command value response and a disturbance response where a proportional integral control amplifier with anti-overshoot compensation is used as a speed control amplifier. In Figure 2, the abscissa and ordinate represent time (second) and speed (n), respectively. At time 0.0 second, a speed command is changed from 0 to 1 and, at time of 0.5 second, a certain constant load is applied to the motor and the response thereat is shown.

The command value response time is

approximately 0.1 second, while the disturbance response time is approximately 0.3 second, and the ratio of these response times is approximately 3.

The motor speed control system is used, for example, to drive a rolling mill for rolling steel and, in this application, when the steel first passes between the mill rolls, there is applied an abrupt drastic load and, if the disturbance response characteristic is not superior, it is difficult to ensure uniform thickness of the rolled steel. Thus, superiority of the disturbance response, rather than the command value response, is regarded to be of major importance.

An object of this invention is to provide a control system having an improved disturbance response characteristic.

According to the present invention, a control system comprises detector means for detecting the value n of a controllable variable; means for producing a reference value; control amplifier means, connected to receive said detected value n and said reference value, and to produce a first command value for use in reducing any difference between the detected value and said reference value; and power converter means for controlling said controlled variable according to said command value, characterised in the provision of control processing means, connected to receive said detected value n and said first command value, and to produce a second command value; said control processing means including means for providing a signal A equal to a predetermined transfer function GX(S) of said detected value n, means for providing a signal B equal to a transfer function (1 + GX(S).GLH(S)) of said first command value, and means for providing, as said second command value, the difference T* between said A and B signals, where GLH(S) is a simulated transfer function which is from T* to n; and wherein the power converter means controls said controlled variable according to said second command value.

The control system may be a motor speed control system.

In order that the invention may be more readily understood, it will now be described, by way of example only, with reference to the accompanying drawings, in which:-

Figure 1 is a schematic block diagram illustrating a prior art speed control system;

Figure 2 is a graph showing the response characteristics of the speed control system of Figure 1,

Figure 3 is a block diagram illustrating an embodiment of the invention;

Figure 4 is a block diagram illustrating the principle of the invention and employing transfer function representation;

Figure 5 is a block diagram illustrating an embodiment of a speed control system according to the invention; and

Figures 6A, 6B, 6C and Figures 7A, 7B and 7C are views representing different response characteristics of the system according to the invention.

In Figure 3, a control processing unit 8 is shown added to the speed control system shown in Figure 1.

In Figure 4, the speed control system shown in Figure 3 is shown in a transfer function representation. Reference numerals 11 and 12 represent summation devices, references 13, 14 and 15 are blocks marked with the respective transfer functions, reference 16 represents a block group including the converter, the motor and the load, reference 2 represents a transfer function of the power converter which is from a torque command value signal T* to a generated motor torque signal T, reference 17 represents a summing junction to which a load torque TL is applied, and reference 7 represents the sum of the force of inertia of the motor and the load. Reference character J designates the force of inertia, and S a Laplace operator, respectively.

When a transfer function which is from the torque command value signal T* of the block group 16 to the speed signal n is defined as GL(S), the transfer function GL(S) can be expressed by the equation (1).

$$G_L(s) = G_{TRQ}(s) \cdot \frac{1}{Js} \quad \ldots\ldots (1)$$

In the conventional system, there is no control processing unit, so the torque command value signal T* equals the output TA of the control amplifier 1, and the transfer function GL(S) is also a transfer function which is from the output of the control amplifier 1 in the conventional system to the speed signal n.

Next, a transfer function n(S)/B(S), which is from the input B of the summation device 12 to the speed signal n, in the case where the block 15 represented by the transfer function GX(S) is added, is expressed by the equation (2).

$$\frac{n(s)}{B(s)} = \frac{G_L(s)}{1 + G_X(s) \cdot G_L(s)} \quad \ldots\ldots (2)$$

Next, a transfer function B(S)/TA(S), which is from the output TA of the control amplifier 1 to the above-described B, is expressed by the equation (3), where the block 14 has the transfer function GX(S) which is identical with that of the block 15, and a transfer function of the block 13 is GLH(S).

$$\frac{B(s)}{TA(s)} = 1 + G_X(s) \cdot G_{LH}(s) \quad \cdots\cdots (3)$$

Thus, a transfer function n(S)/TA(S), which is from the output TA of the control amplifier 1 to the speed n, can be expressed by the equation (4).

$$\frac{n(s)}{TA(s)} = \left(n(s) \middle/ B(s) \right) \times \left(B(s) \middle/ TA(s) \right)$$

$$= \frac{1 + G_X(s) \cdot G_{LH}(s)}{1 + G_X(s) \cdot G_L(s)} \cdot G_L(s) \quad \cdots (4)$$

Here, if a transfer function GLH(S) of the block is selected equally to the transfer function GL(S), the equation (4) becomes the equation (5).

$$\frac{n(s)}{TA(s)} = G_L(s) \quad \cdots\cdots (5)$$

Therefore, if the transfer function GLH(S) of the block 13 is set to the transfer function GL(S), which is from the torque command value signal T* to the speed signal n, even when the control processing unit 8 according to the present invention is added, the transfer function which is from the output TA of the control amplifier 1 to the speed signal n is not varied compared to the conventional example, and there exists no change in terms of the command value response.

Here, a speed response nLNEW(S), in the case where a load TL(S) is applied, can be obtained as follows:-

If a transfer function which is from the detected speed value n, which is the feedback input of the control amplifier 1 to the output TA thereof, is defined as a transfer function GSP(S), the transfer function nLNEW(S) can be expressed by the equation (6).

$$n_{LNEW}(S) = \frac{\frac{1}{JS}}{1 + G_{SP}(S) \cdot G_L(S)} \cdot \frac{1}{1 + G_X(S) \cdot G_L(S)} \cdot T_L(S) \quad \cdots (6)$$

A speed response nLOLD(S) in the conventional example can be obtained when assuming that GX(0) = 0 in the equation (6), and can be expressed by the equation (7).

$$n_{LOLD}(S) = \frac{\frac{1}{JS}}{1 + G_{SP}(S) \cdot G_L(S)} \cdot T_L(S) \quad \ldots (7)$$

Therefore, when compared to the conventional example, the disturbance response according to the present invention is changed only by the equation (8).

$$\frac{1}{1 + G_X(S) \cdot G_L(S)} \quad \ldots (8)$$

Thus, if the transfer function GX(S) is appropriately selected, the disturbance response can be improved while the command value response is not affected.

The transfer function GX(S) can be basically arbitrarily selected, however, it should be selected within such an extent that the transfer function expressed by the equation (8) does not have unstable or oscillatory components.

In Figure 5, there is specifically shown the embodiment according to the present invention. This embodiment is an example such that improvement advantages of the preferable disturbance response can be acquired, in addition, its setting adjustment can be readily made. The control processing unit 8 is the portion particularly added according to the present invention. Reference numerals 18, 19 and 20 designate summation devices, 13 a simulated transfer function block which includes the transfer function GLH(S) that simulates the transfer function GL(S), which is from the torque command value signal T* identical with the aforementioned to the speed n, and reference numerals 21, 22 are coefficient blocks that multiply the respective input values by the respective coefficients (such as GLC, GLA) represented within the respective blocks.

A signal D, which is the output of the coefficient block 21 is fed into the coefficient block 22 so as to be multiplied by the coefficients GLA, and the thus multiplied signal and the output TA of the control amplifier 1 are fed into the summation device 18 so as to be processed in subtraction producing a signal C. The signal C is then fed into the simulated tranfer function block 13, and the output thereof and the detected speed value n are fed into the summation device 20 so as to be processed in subtraction. The output of the summation device 20 is fed into the coefficient block 21 so as to be multiplied by the coefficient GLC producing the signal D. On the other hand, the signal C is also fed, together with the signal D, into the summation device 19 so as to be processed in addition thereby producing the torque command value signal T*.

In general, a transfer function GTRQ(S), represented by the block 2, which is from the torque command value signal T* to a generated motor signal T, can be approximated by a first-order lag transfer function, and a transfer function 1/JS, represented by the block 7, which is determined by the force of inertia J signifies integration, so that, in order to realise the transfer function GLH(S) of the simulated transfer function block 13, a first-order lag circuit (equivalent to a low pass filter) and an integrator are appropriate to be employed.

If the above-described configuration is

modified into the principle block diagram of Figure 4, the transfer function GX(S) can be expressed by the equation (9).

$$G_{X(S)} = \frac{(1 - G_{LA})G_{LC}}{1 + G_{LA} \cdot G_{LC} \cdot G_{LH(S)}} \qquad (9)$$

Assuming that the coefficient GLA is zero, the transfer function GX(S) becomes a mere coefficient GLC, and this permits a simplest configuration of the present invention.

Advantages derived from the aforementioned configuration will be described on the basis of experimental results.

Figures 6A - 6C are diagrams illustrating comparisons of responses in the case where the coefficient GLA is defined as zero and the coefficient GLC is varied. Responses are measured under the condition in which the speed command value is changed from 0 to 1 at a time of 0.0 second, and then at a time 0.5 second a constant load is applied.

Figure 6A shows the response in the case where the coefficient GLC = 0, i.e. the response is identical with that of Figure 2. Figure 6B shows the response in the case where the coefficient GLC is set to the value being regarded as an optimum value. Figure 6C shows the response in the case where the coefficient GLC is set to a value greater than the optimum value, and there exist oscillatory phenomena, and it can be seen that the setting is inappropriate.

Figures 7A - 7C are diagrams illustrating comparisons of responses in the case where the coefficient GLC is set to the value being regarded as the optimum value in Figure 6B, and the coefficient GLA is varied.

Figure 7A shows the response again in the case where the coefficient GLA = 0, which is identical with that of Figure 6B for the sake of comparison. Figure 7B shows the response in the case where both the coefficients GLC and GLA are set to the value being regarded as the optimum value. Figure 7C shows the response in the case where the coefficient GLA is set to the value greater than the optimum value.

As shown in the experimental results, the adjustments for the optimum response are made such that, first, the coefficient GLA is set to zero and then the coefficient GLC is increased to the point immediately before that an oscillatory phenomenon appears. This can reduce the speed reduction that inevitably occurs upon the disturbance response, however, overshooting appears when the speed recovers, so that, next, the coefficient GLA is increased until that the overshooting disappears, whereby the optimum response can be readily achieved.

When comparison is made between the response in the conventional example of Figure 6A and the response in the embodiment according to the present invention of Figure 7B, it is understood that only the disturbance response is improved with substantially no change in the command value response. The speed reduction upon the disturbance response is reduced to 70%, and the response time until the instant at which the speed recovers is shortened to 30%, in addition, the ratio of the command value response time and the disturbance response time is approximately 1, and advantages derived from its improvement is extremely great.

Another advantage of the present invention besides the aforementioned is such that the command value response change with respect to variations in the force of inertia of the load can be reduced. For example, when the inertia is increased, greater torque is required to accelerate, however, the response change can be suppressed similarly to the case where the load torque is applied to this increment of the load. Further, this means that, even when the transfer function of the simulated transfer function block which is required for the present invention differs from the actual value to some extent, the advantages of the present invention can be exhibited so that the simulated transfer function is free from strict preciseness, consequently, the implementation thereof can be readily achieved.

In addition, even when a resonant system is constituted between the motor and the load, variations in the torque caused by resonance can be suppressed as variations in the load. For example, in the case of an elevator system, there is installed a lifting rope that constitutes a resonant system between the lifting motor and the cage which is the load, whereby riding comfort for the passengers is deteriorated, however, this can also be suppressed by utilising the embodiment according to the present invention as an extremely effective countermeasure.

Although the hereinbefore description has been made as to the case where the DC motor is controlled with a constant field, similarly other applications can also be implemented in such a manner that, when varying the field between the torque command value converter and the current command, there is additionally provided a variable coefficient block that corresponds to variations in the field, or that, when controlling an AC motor, there is additionally provided a block group that calculates so as to derive an AC current command value from the torque command value.

Furthermore, the present invention is not limited to, in terms of a control system, the motor speed control system.

Claims:

1. A control system comprising:

detector means for detecting the value n of a controllable variable;

means for producing a reference value;

control amplifier means, connected to receive said detected value n and said reference value, and to produce a first command value for use in reducing any difference between the detected value and said reference value; and

power converter means for controlling said controlled variable according to said command value,

characterised in the provision of

control processing means, connected to receive said detected value n and said first command value, and to produce a second command value;

said control processing means including means for providing a signal A equal to a predetermined transfer function GX(S) of said detected value n, means for providing a signal B equal to a transfer function (1 + GX(S).GLH(S)) of said first command value, and means for providing, as said second command value, the difference T* between said A and B signals, where GLH(S) is a simulated transfer function which is from T* to n; and wherein the power converter means controls said controlled variable according to said second command value.

2. A motor speed control system comprising:

speed detector means for detecting the speed n of the motor;

means for producing a reference speed value;

speed of the motor according to said command value,

speed control amplifier means connected to receive said detected speed value and said reference speed value, and to produce a first command value for use in reducing any difference between the detected speed value and said reference speed value; and

power converter means for controlling said speed of the motor according to said command value,

characterised in the provision of

control processing means, connected to receive said detected speed value n and said first command value and to produce a second command value;

said control processing means including means for providing a signal A equal to a predetermined transfer function GX(S) of said detected value, means for providing a signal B equal to a transfer function (1 + GX(S).GLH(S)) of said first command value, and means for providing, at said second command value, the difference T* between said A and B signals, where GLH(S) is a simulated transfer function which is from T* to n; and wherein the power converter means controls said speed of the motor according to said second command value.

3. A control system according to claim 1, characterised in that said predetermined transfer function GX(S) is a transfer function that can be expressed by

$$\frac{(1-G_{LA})G_{LC}}{1+G_{LA}\cdot G_{LC}\cdot G_{LH}(S)}$$

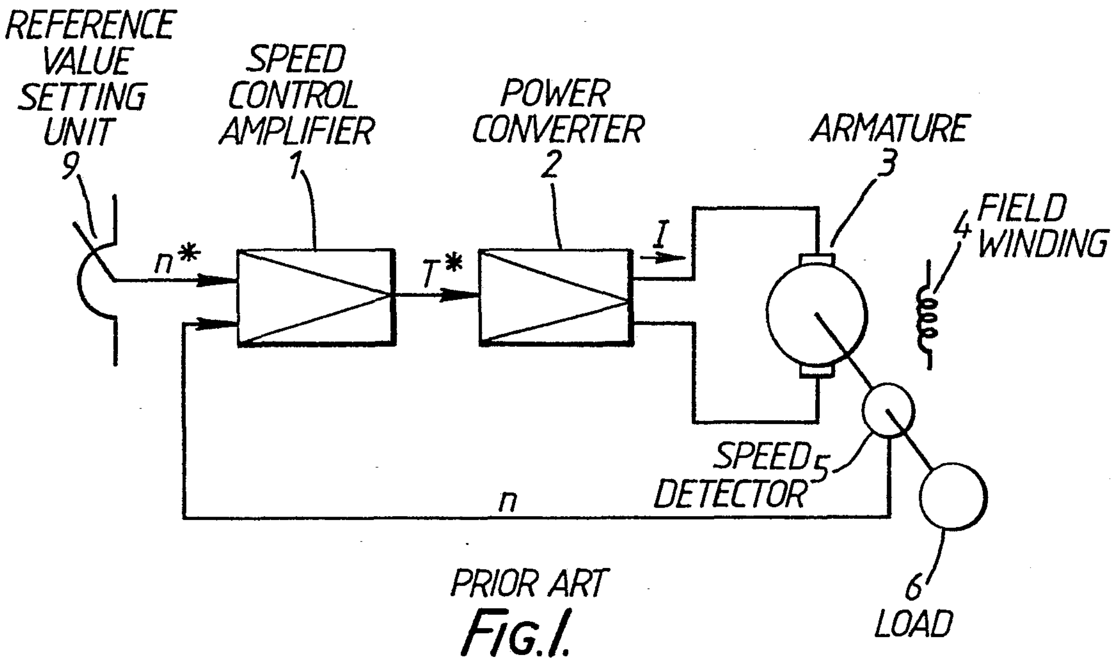
where GLA and GLC are defined as predetermined coefficients.

4. A motor speed control system according to claim 2, characterised in that said predetermined transfer function GX(S) is a transfer function that can be expressed by

$$\frac{(1-G_{LA})G_{LC}}{1+G_{LA}\cdot G_{LC}\cdot G_{LH}(S)}$$

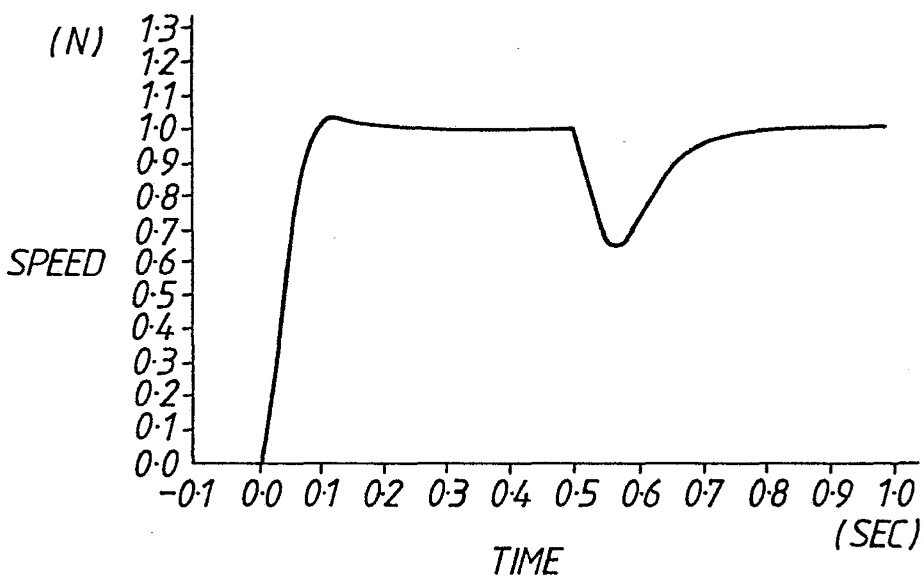
5. A motor speed control system according to claim 2 or 4, characterised in that said motor is an AC motor.

6. A motor speed control system according to claim 2 or 4, characterised in that said motor is a DC motor.



PRIOR ART

FIG. 1.



PRIOR ART

FIG. 2.

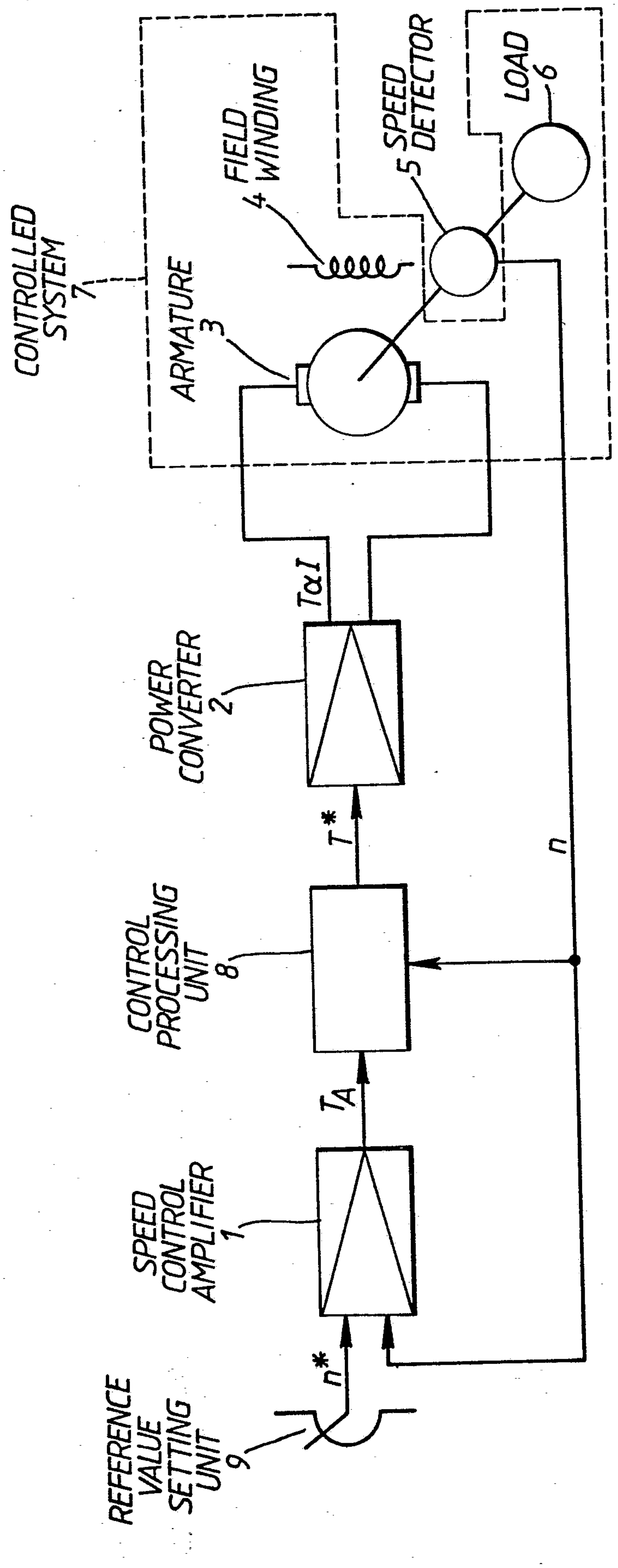

CONTROLLED SYSTEM 7
FIELD WINDING 4
SPEED DETECTOR 5
LOAD 6
ARMATURE 3
$T \alpha I$
POWER CONVERTER 2
T^*
n
CONTROL PROCESSING UNIT 8
T_A
SPEED CONTROL AMPLIFIER 1
n^*
REFERENCE VALUE SETTING UNIT 9

FIG.3.

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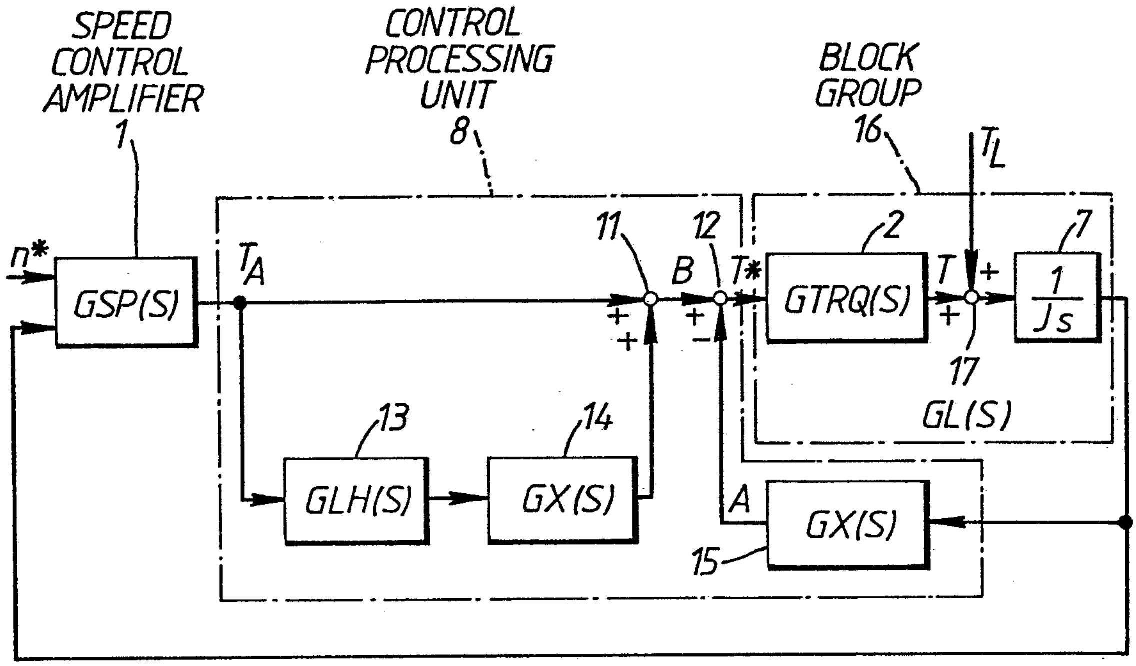

FIG.4.

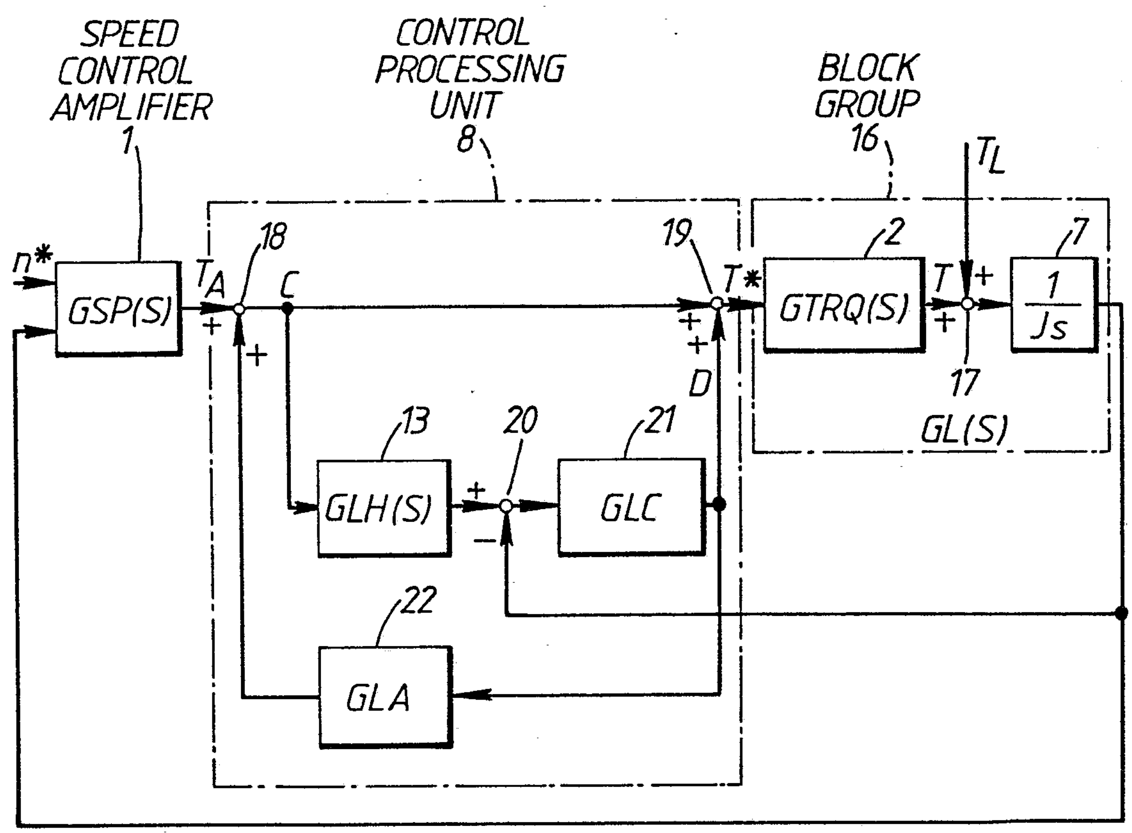

FIG.5.

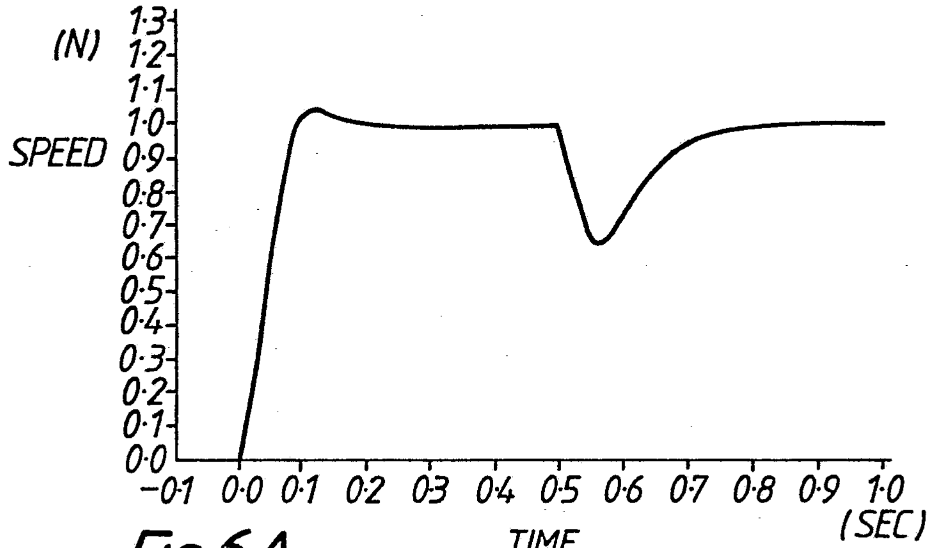

FIG.6A.

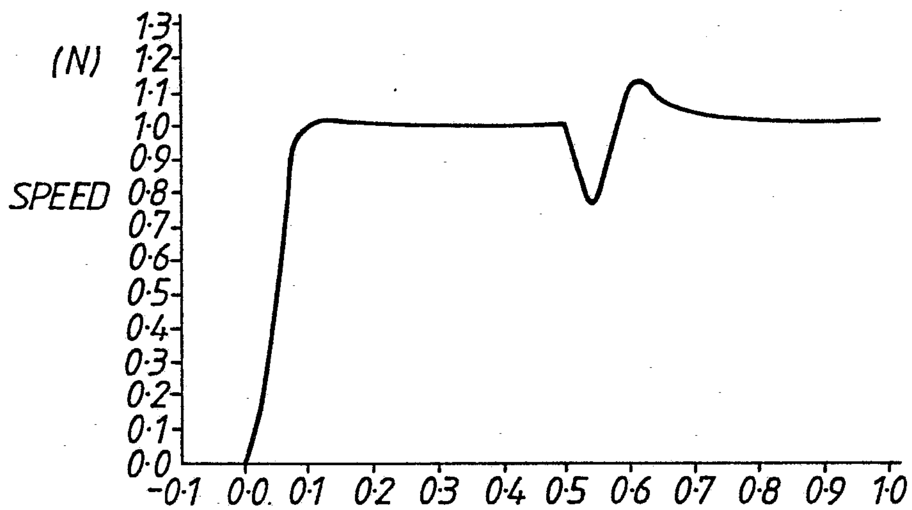

FIG.6B.

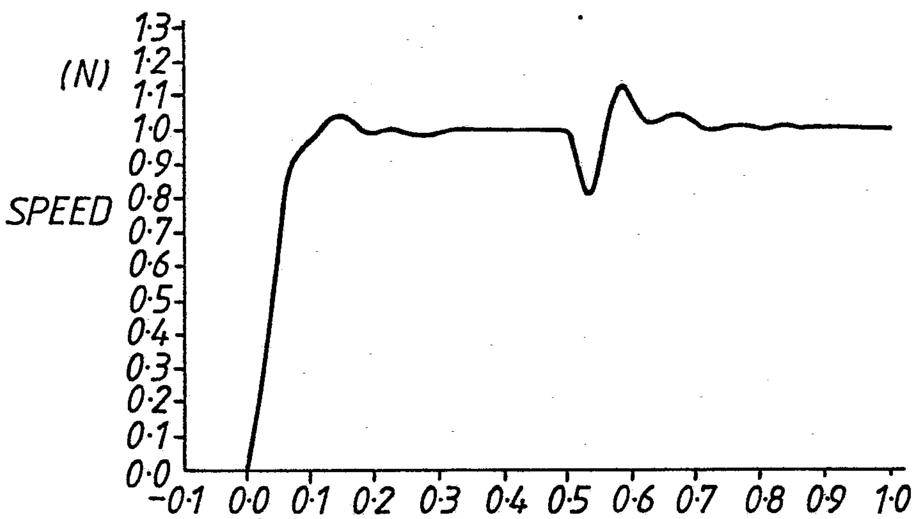

FIG.6C.

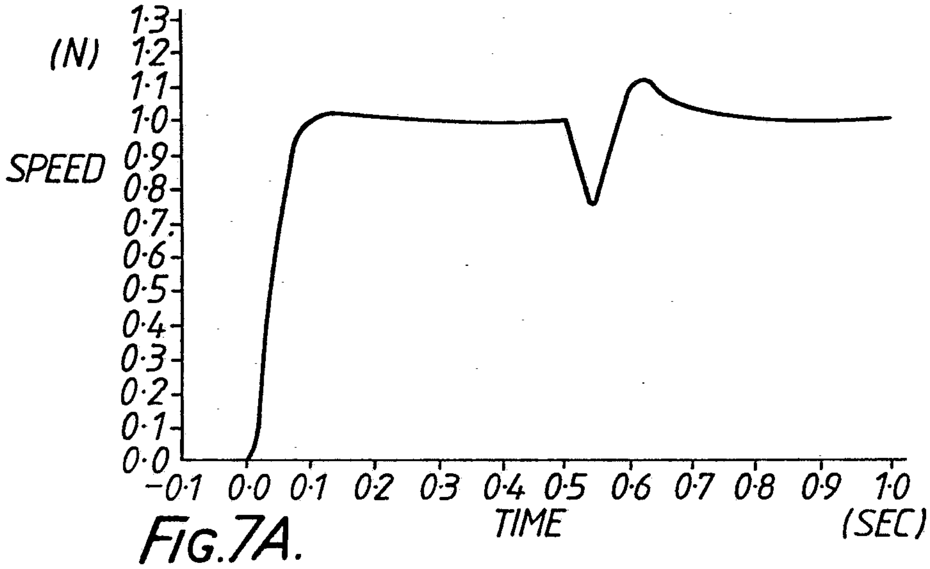

FIG.7A.

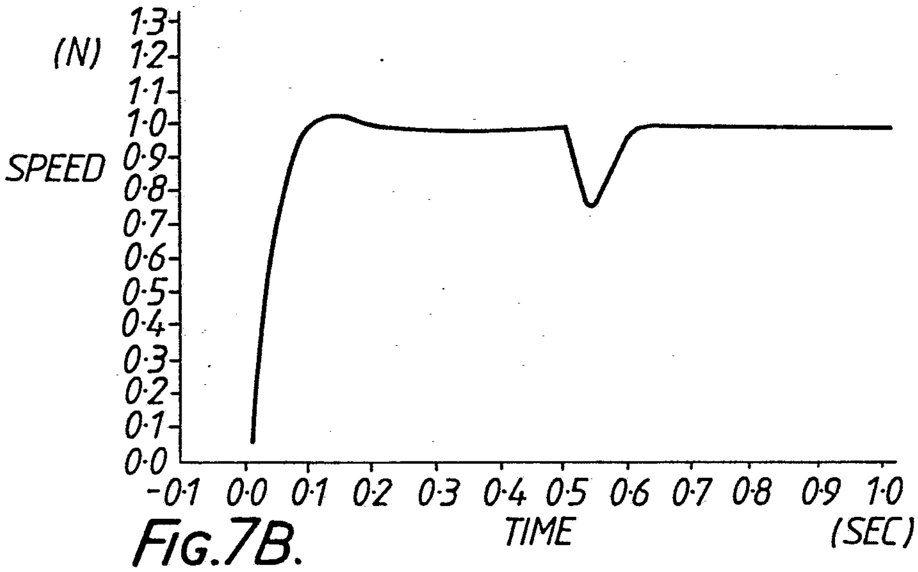

FIG.7B.

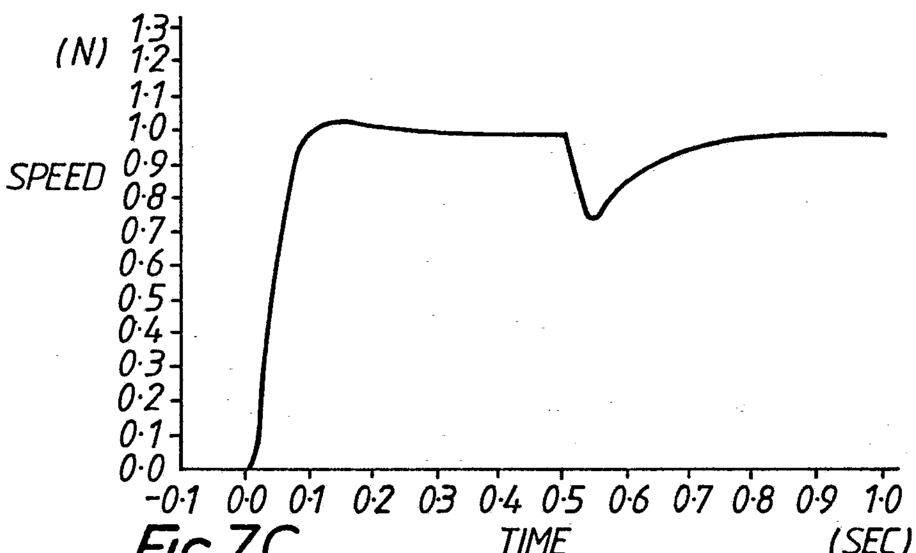

FIG.7C.